Evaluating a Complex System of Systems Using State Modeling and Simulation

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Need for System of Systems (SoS) Evaluation

- Evaluating design concepts for complex systems of systems is required for Army transformation and envisioned military systems like
  - Future Combat Systems (FCS)
  - Objective Force Warrior (OFW)
- From conceptual design to production, SoS analysis will be critical to achieving individual system, and SoS, performance objectives

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Problem

- Systems of systems characterized by complex combinations and interdependencies of technologies, operations, tactics, and procedures
- Evaluation of a SoS presents unprecedented challenges in
  - Exploration and analysis of multidimensional trade spaces
  - Predict performance across multitude of design and technology options
  - Performance characterized by several measures of effectiveness (MOEs)
  - Improve and optimize mission effectiveness across wide parameter spaces
- Analyzing performance of several design options of a complex SoS across external parameters and multiple MOEs can generate a massive number of trade space combinations to be assessed, presenting extreme computational issues

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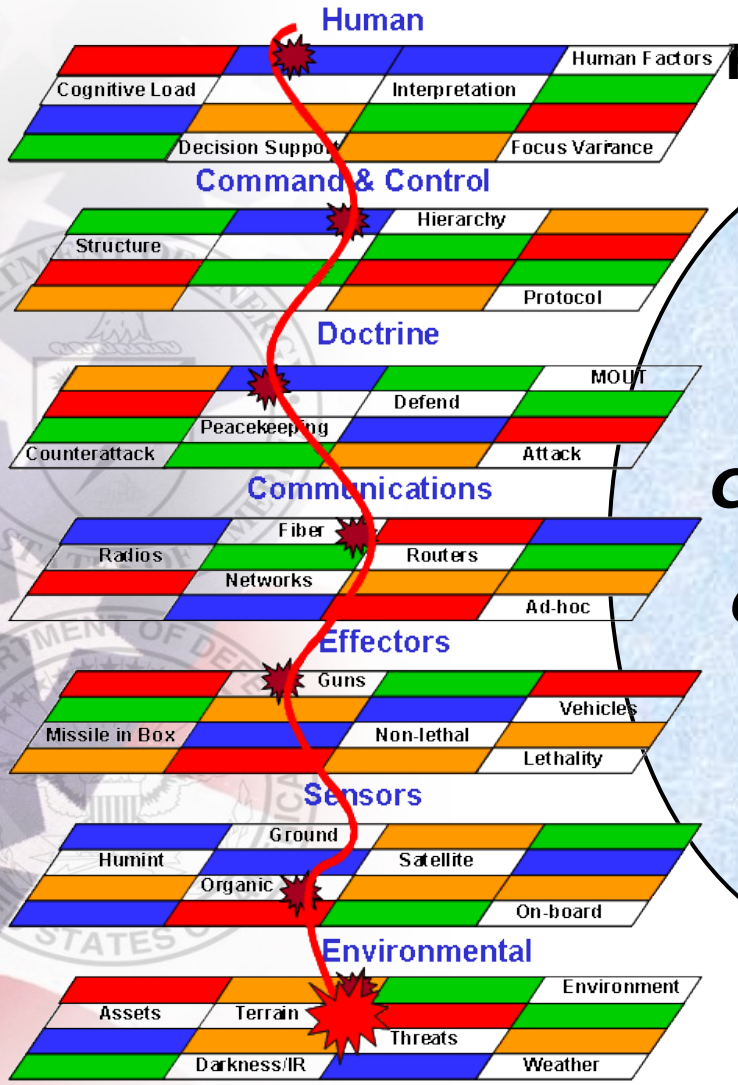
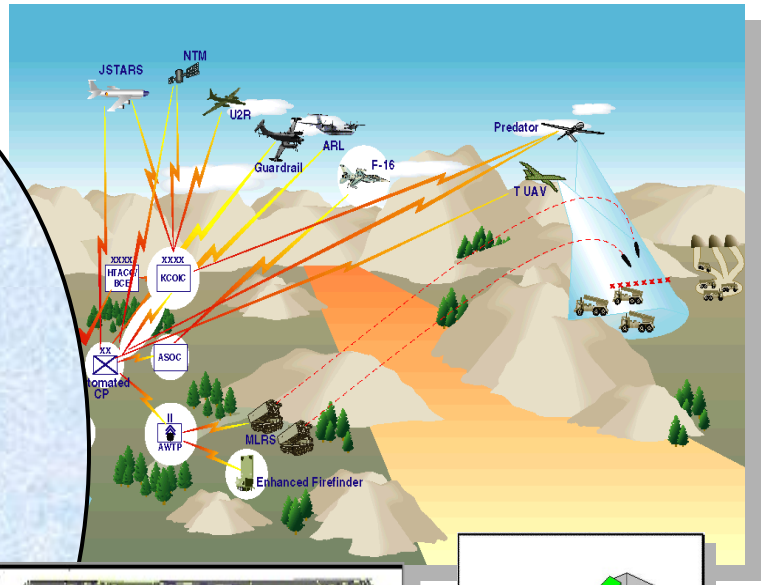
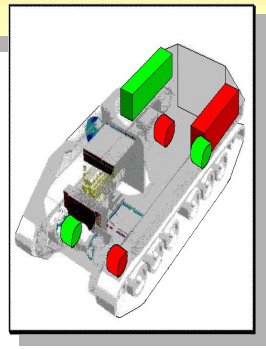
DARPA IDEAS Future Combat System (FCS) Project Focused on Analysis of Multiple MOES across Large Trade Spaces



Functional View

Effect
Sense
Communicate
Command & Control
Move
Protect





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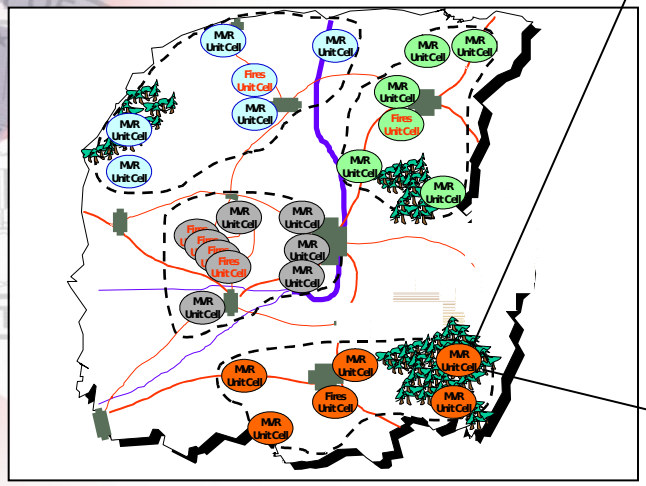
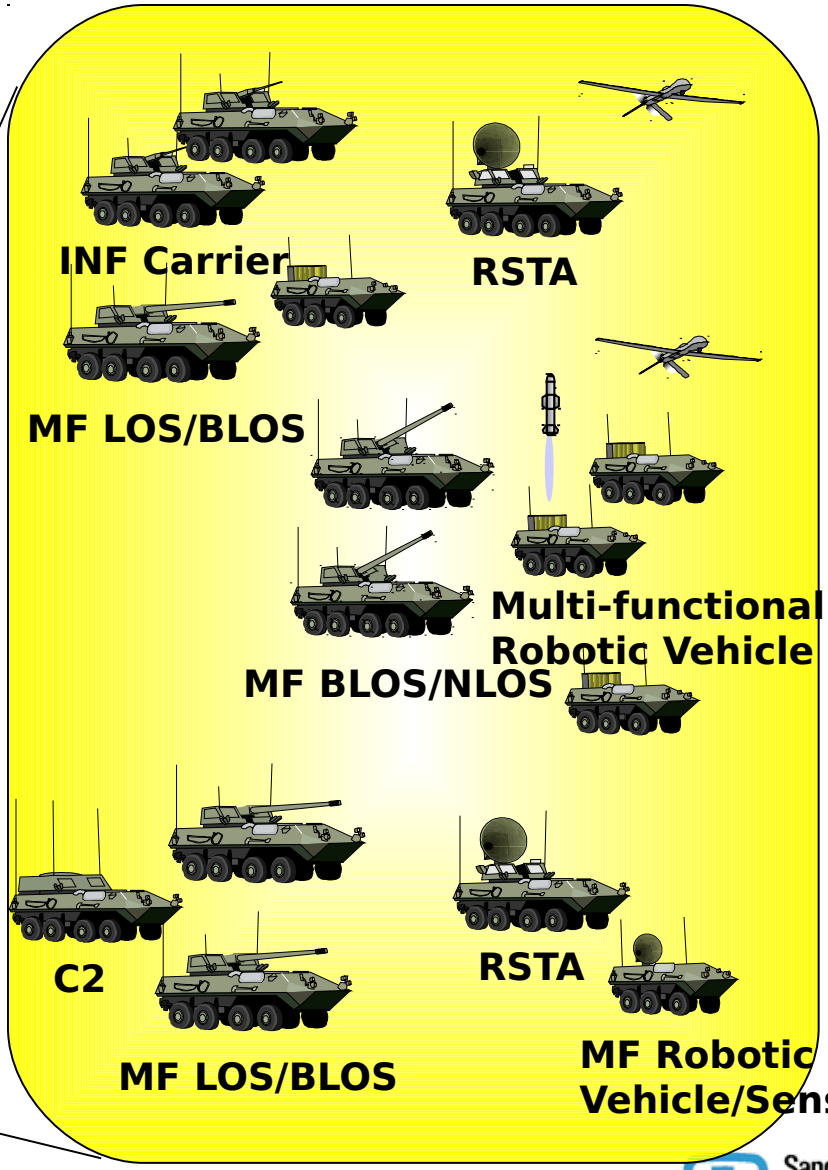
Notional FCS Maneuver Unit Cell

- **RSTA Vehicles** with UAV *controls all organic sensors*
- **C2 Vehicle** *command and control unit cell and link to Unit of Action*
- **Multi-functional (MF) Vehicles** *Able to fire LOS, BLOS, NLOS*
- **Infantry Carrier Vehicles** *for dismounted action and protection*
- **Multi-functional Robotic Vehicles** *unmanned ground sensor, unmanned Net Fires (BLOS/NLOS)*





Colonel Peter Corpac, April 3, 2001
Deputy Director, Depth and Simultaneous Attack Battle Lab

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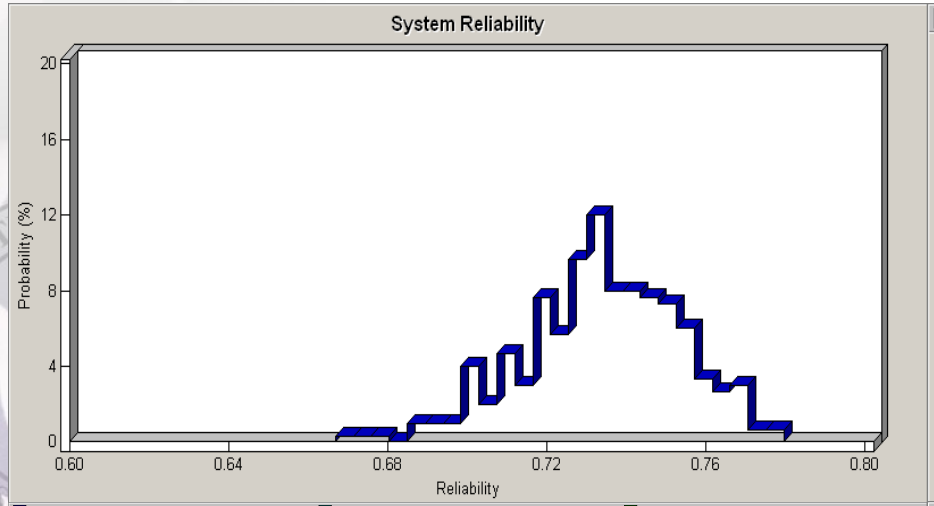
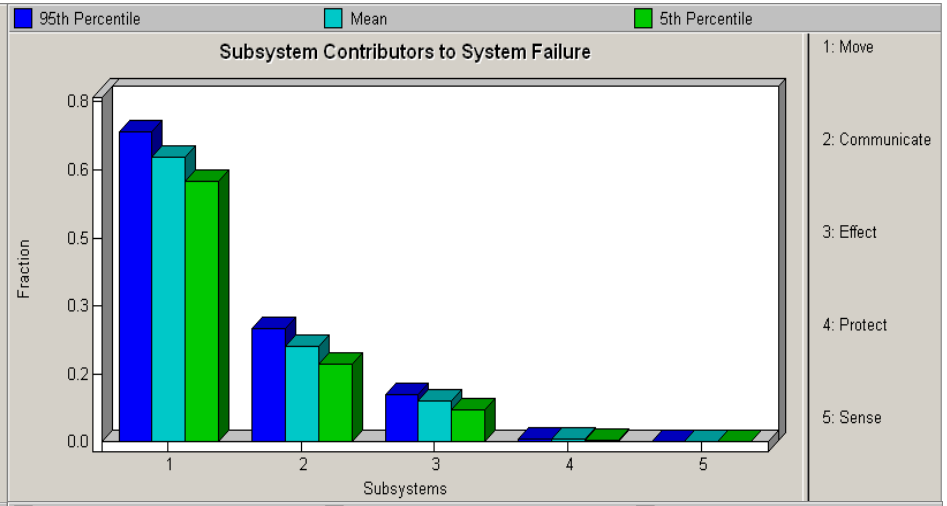
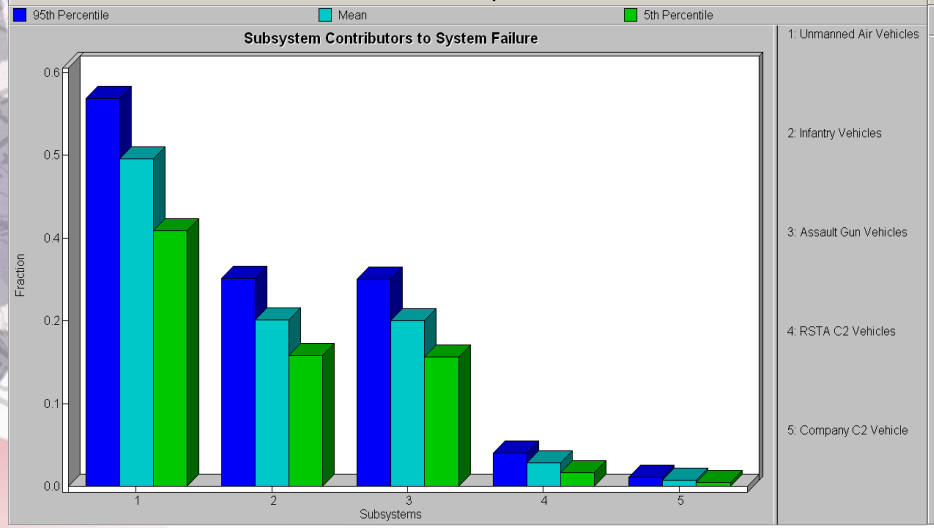
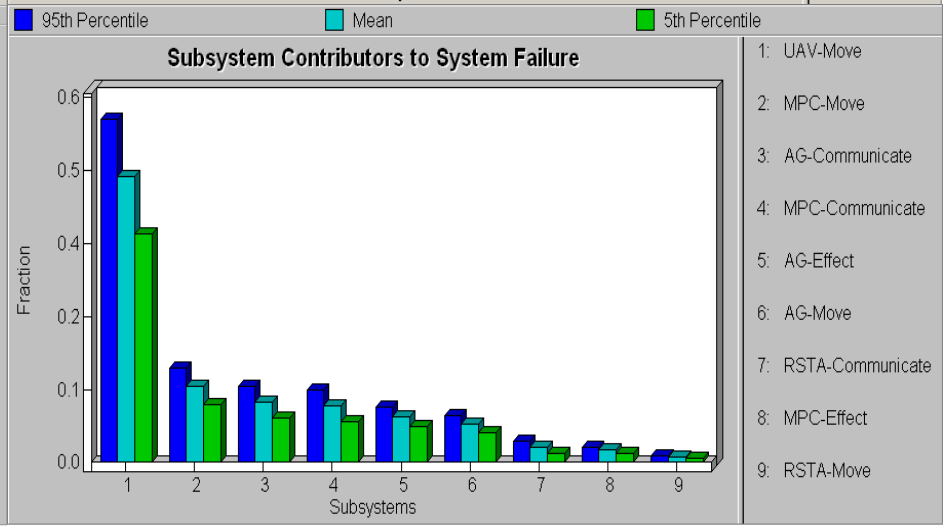
FCS Reliability Analysis Results









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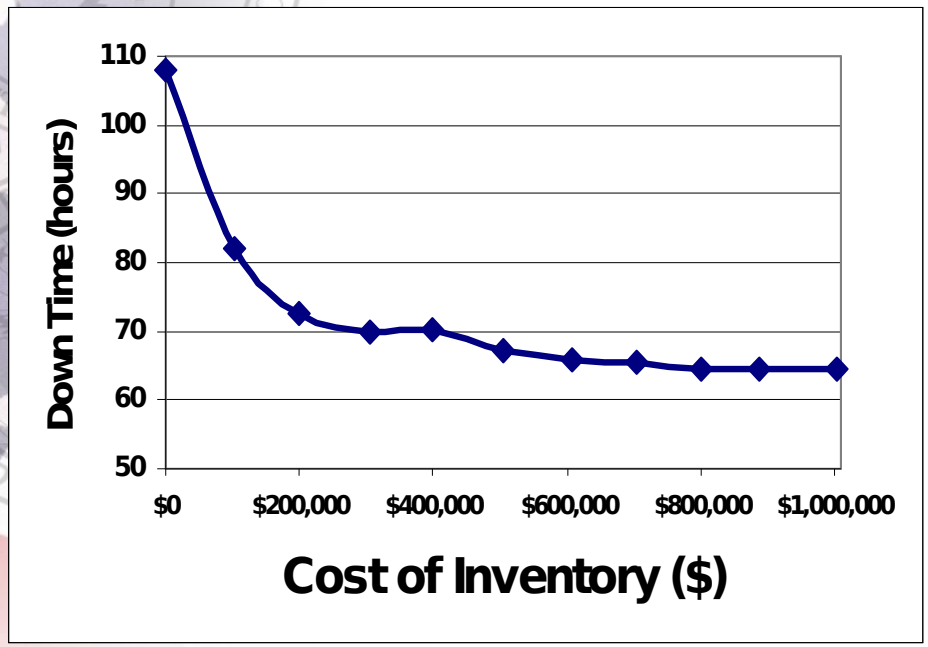
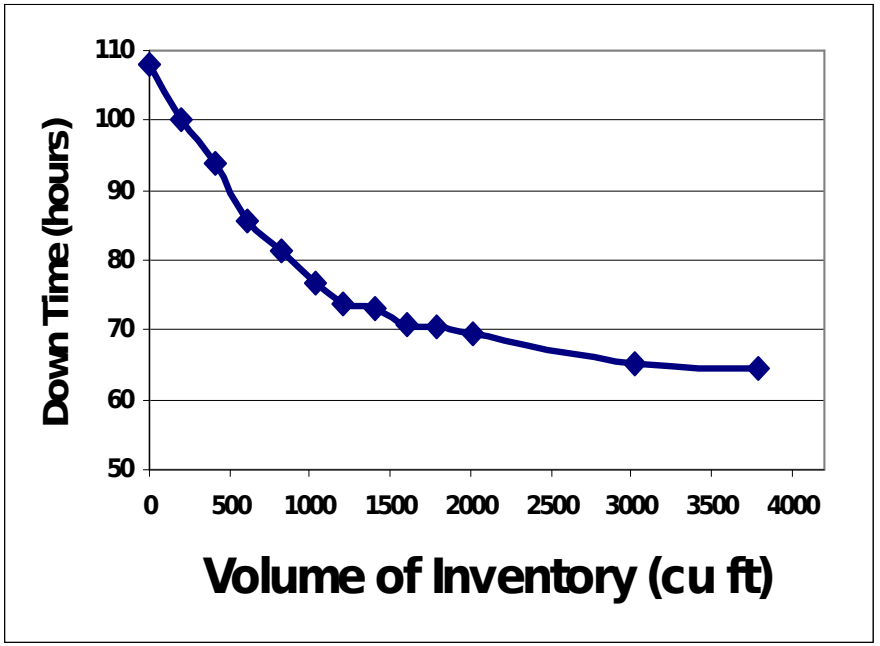
FCS Spare Parts Optimization

- **Minimal logistics footprint required for FCS**
- **Optimal spare parts determined to minimize downtime for set cost of inventory**
  - **Cost in terms of both $ and space**





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Internal Investment in System of Systems (SoS) R&D

- **Nearly $1M investment in FY03-FY04**
  - Extending SoS methodology
  - Extending existing tools
- **R&D focusing on SoS challenges**
  - Multiple MOEs
  - Multiple system states
  - Optimization of multiple MOEs across massive trade spaces
  - Large number of systems (UA ~700 platforms)
  - Massive redundancy
  - Efficient analysis of multiple scenarios

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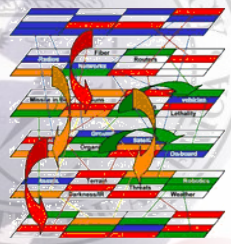
Current Platform, FoS, & SoS Modeling Approach

External Factors
1. Weather
2. Threat
3. Terrain
4. Doctrine
5. Tactics
…



Functions
1. Effect
2. Sense
3. Move
4. Protect
5. Communicate
6. Command & Control
…

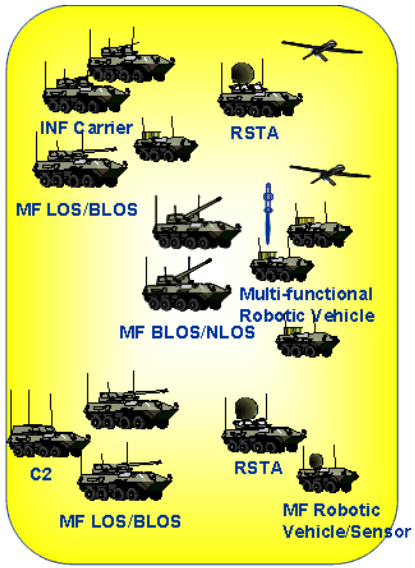
MOEs
1. Availability
2. Reliability
…

Model Platforms

Components
1. Engine
2. Wheels / Tracks
3. Weapons
4. Targeting
5. Detection
…

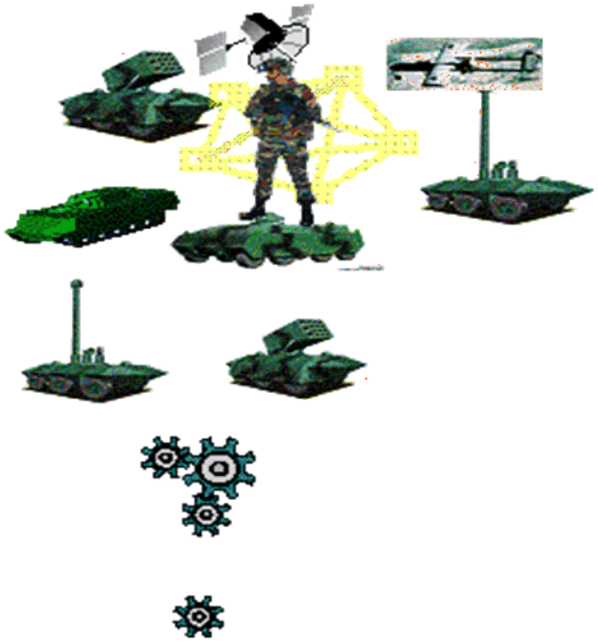
MOEs
1. Availability
2. Reliability
3. Lethality
…

Model Family of Systems



MOEs
1. Availability
2. Reliability
3. Lethality
…

Model System of Systems



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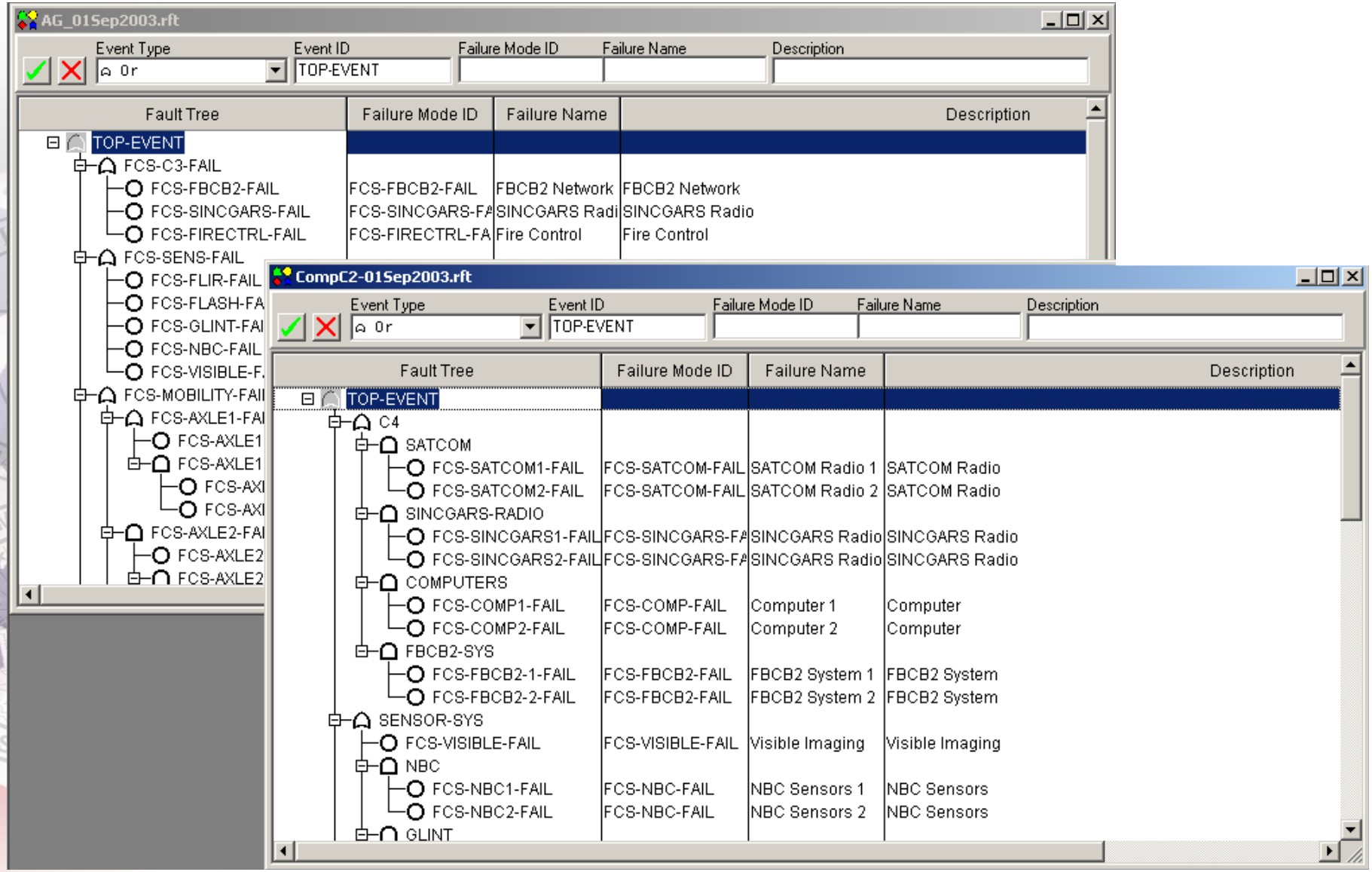
AG (NLOS-C) & Comp-C2 Models



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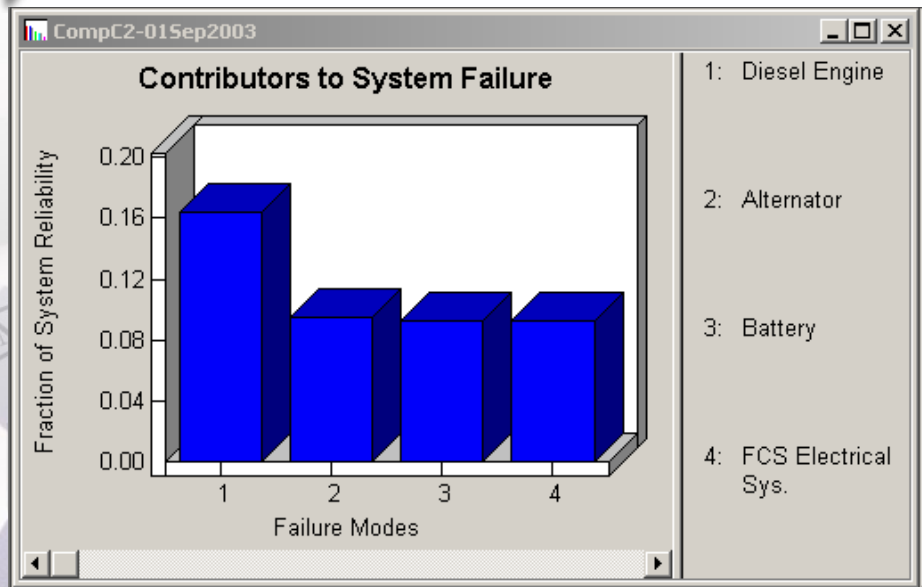
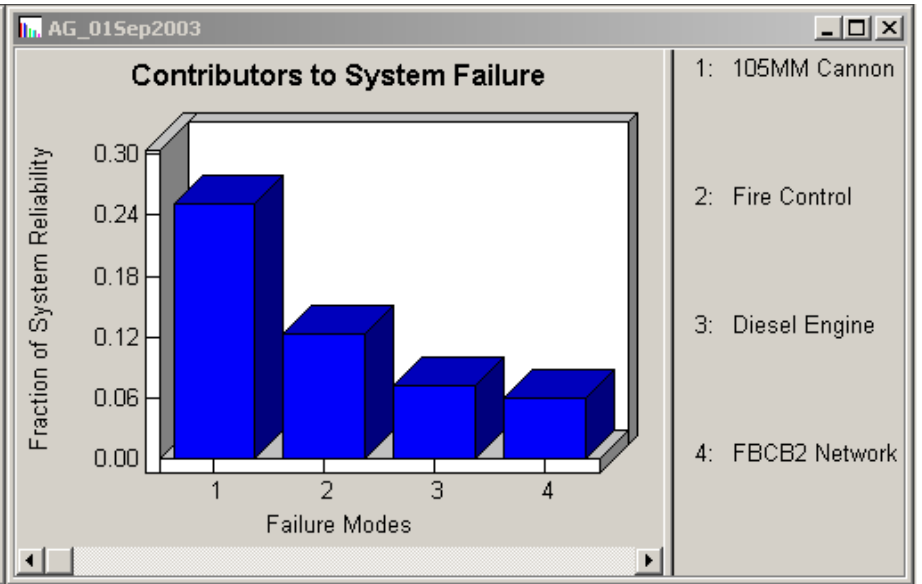
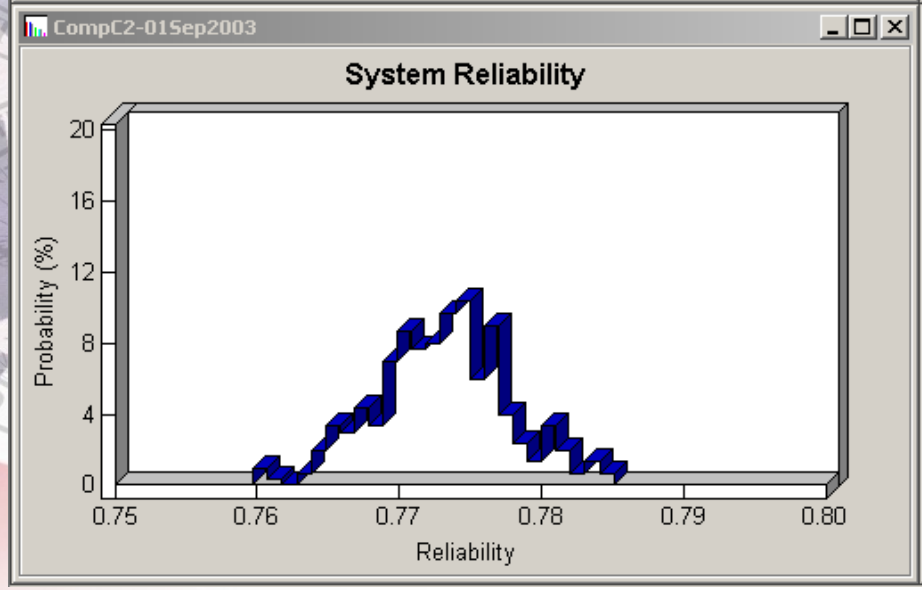
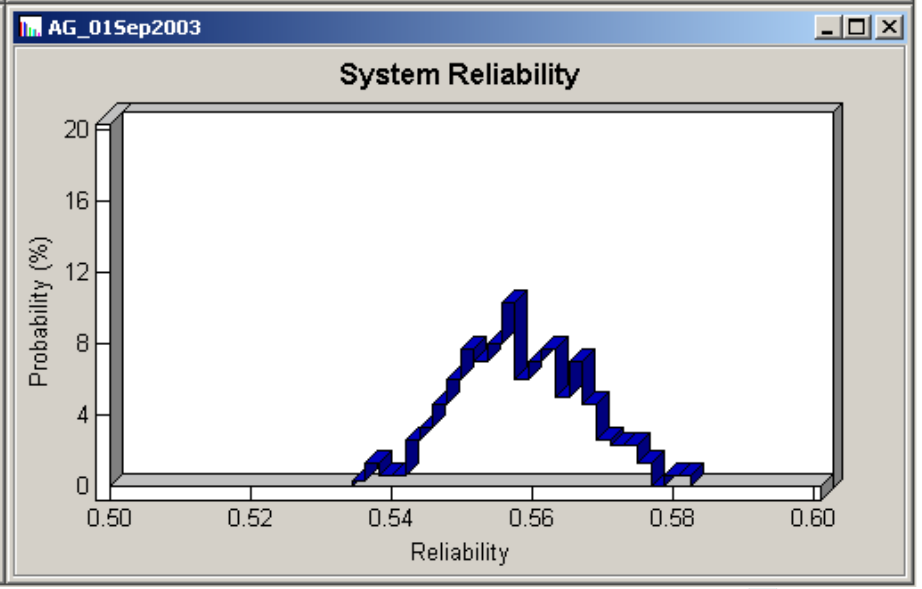
AG (NLOS-C) & Comp-C2 Example Results









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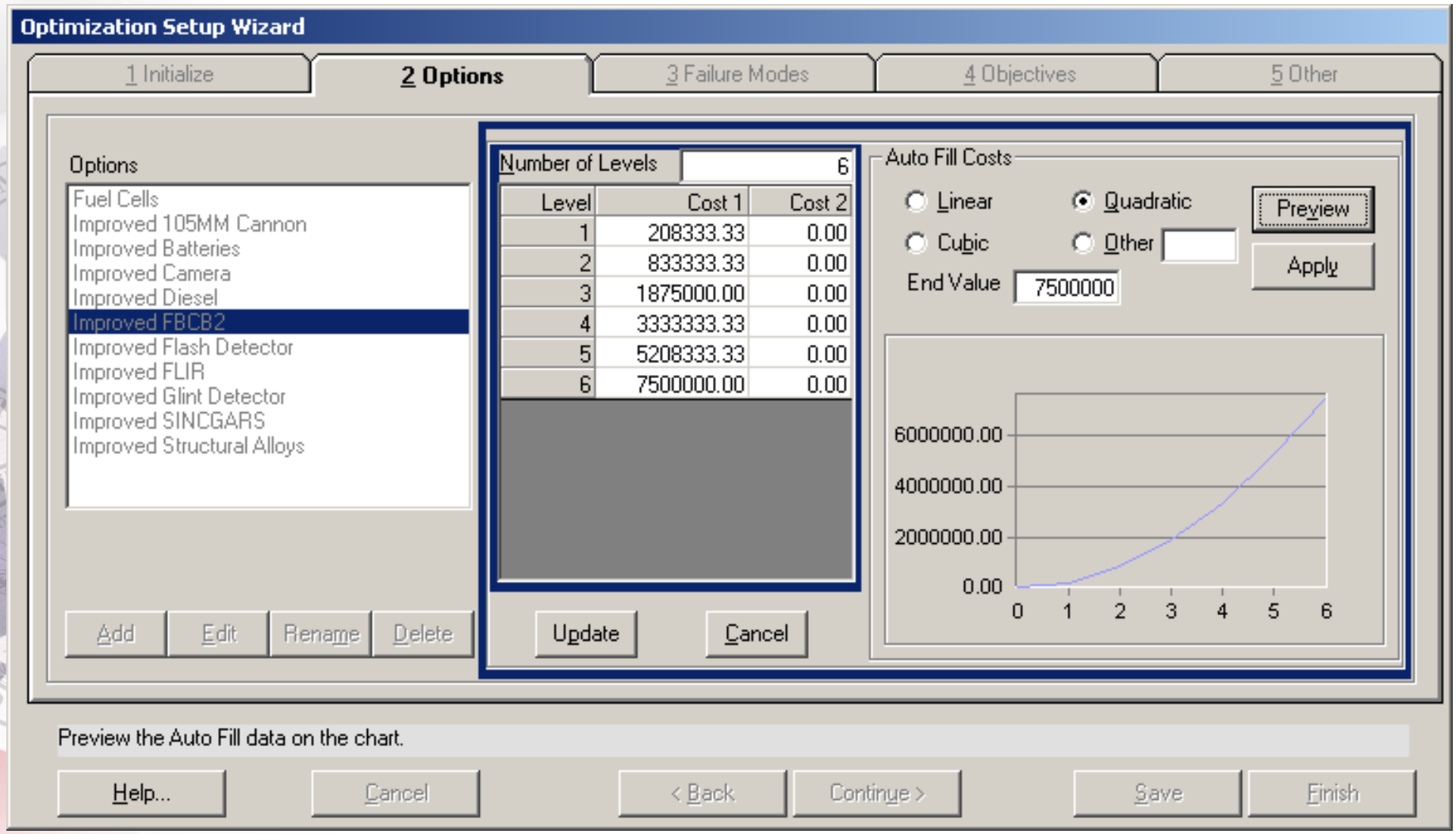
Optimization Input



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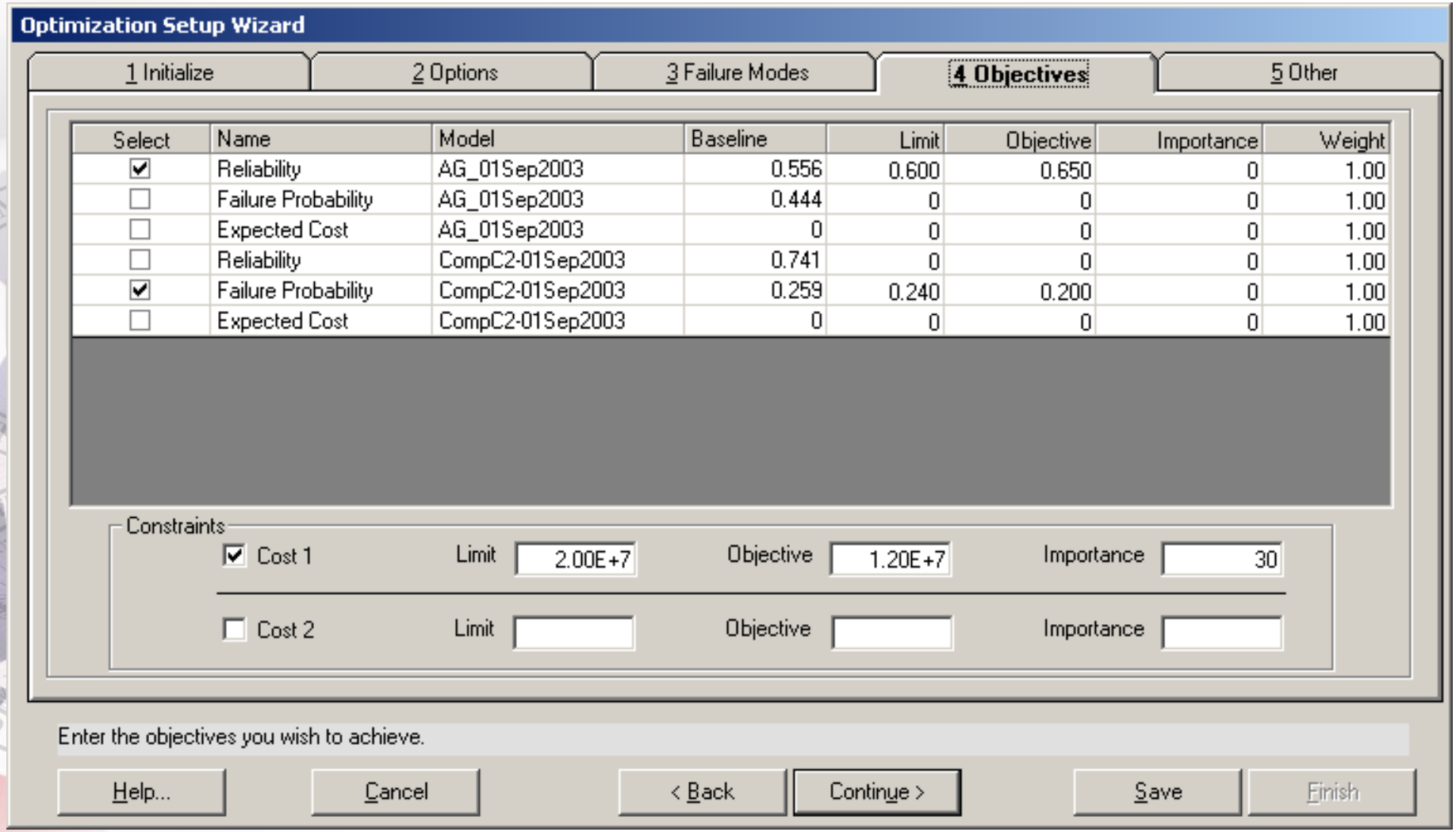
Optimization Objectives



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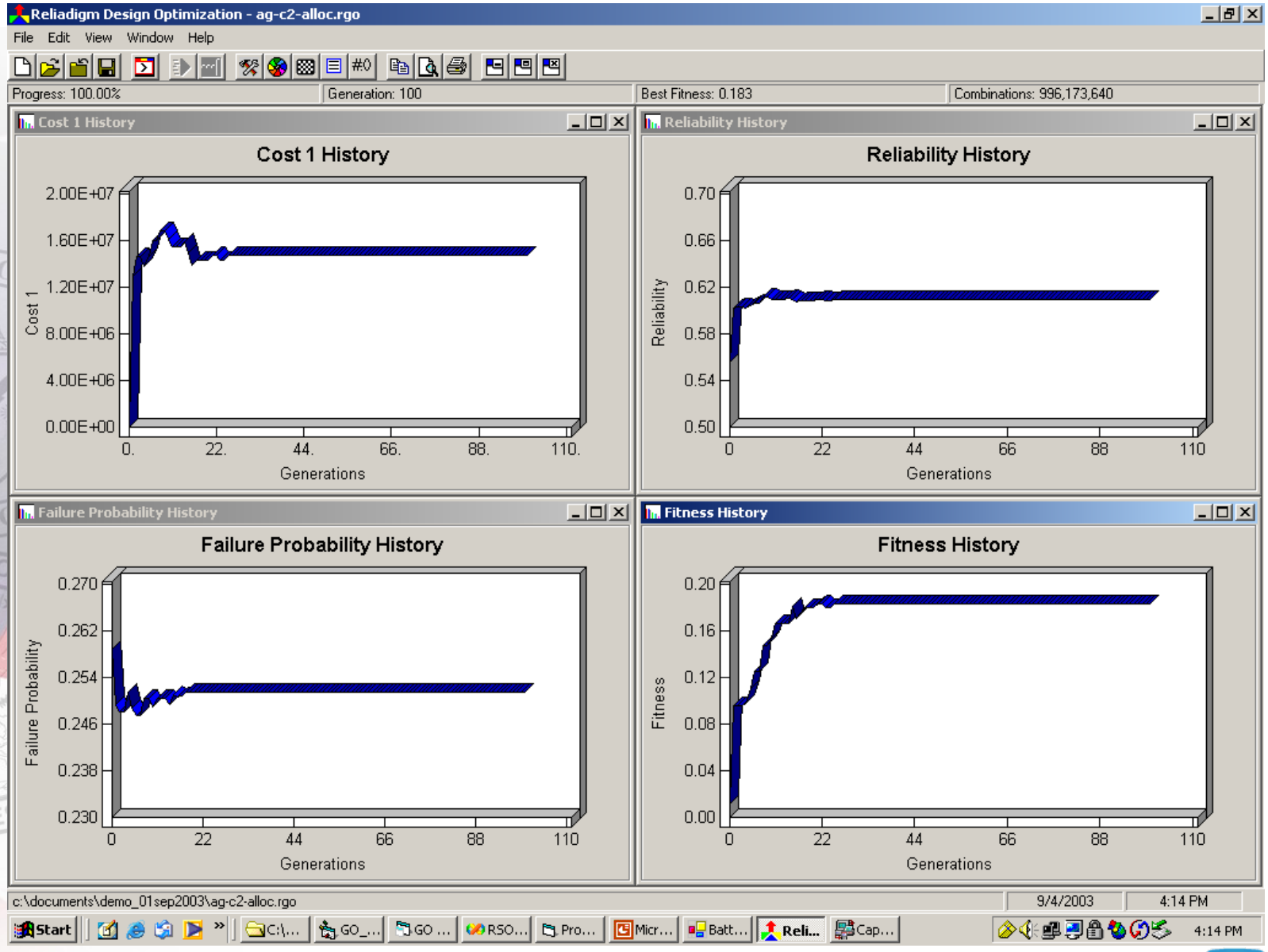
Optimization Results



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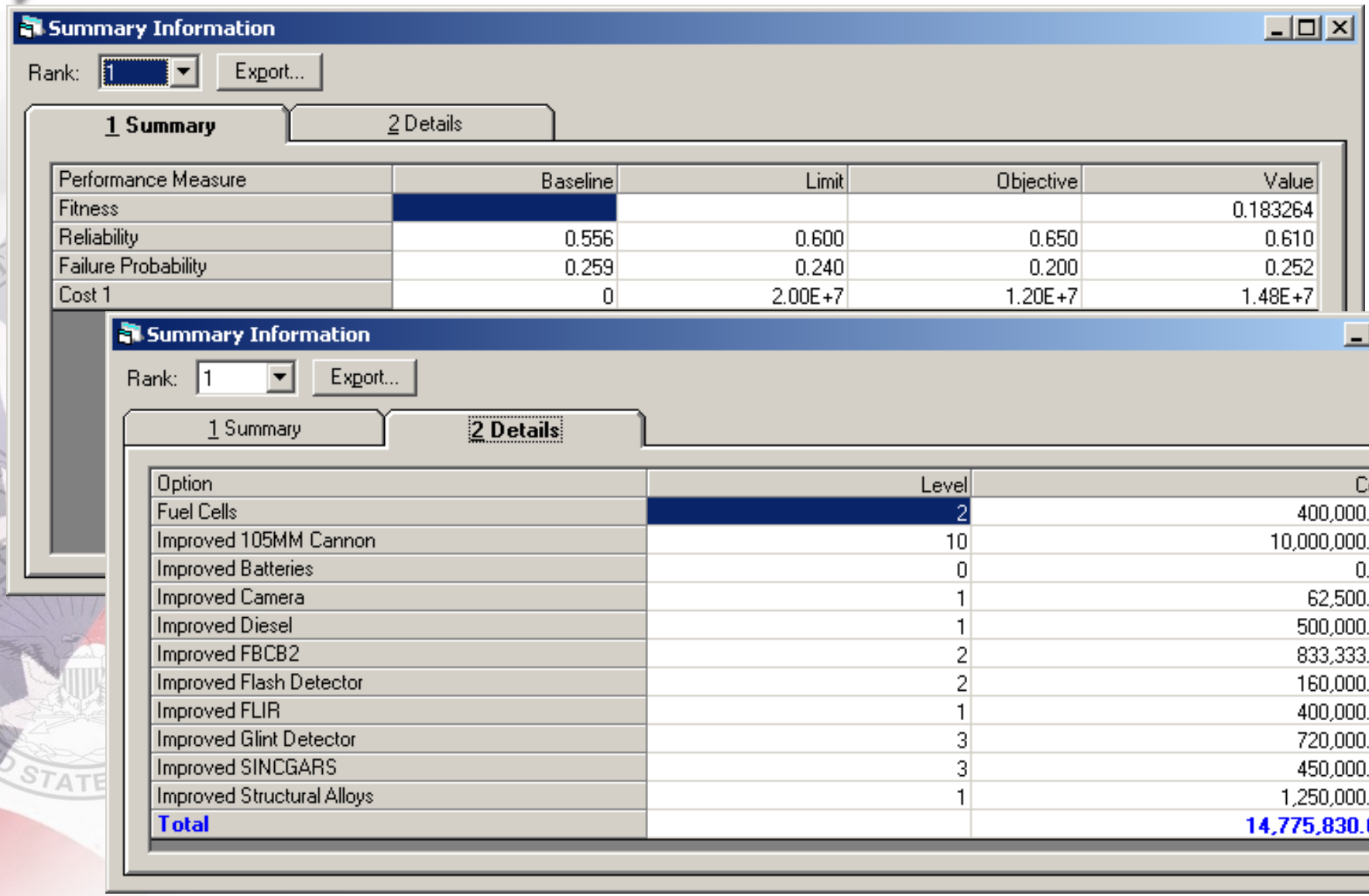
Summary Optimization Results


Summary Information
Rank: 1
Export...
1 Summary
2 Details
Performance Measure | Baseline | Limit | Objective | Value
Fitness | | | | 0.183264
Reliability | 0.556 | 0.600 | 0.650 | 0.610
Failure Probability | 0.259 | 0.240 | 0.200 | 0.252
Cost 1 | 0 | 2.00E+7 | 1.20E+7 | 1.48E+7
Summary Information
Rank: 1
Export...
1 Summary
2 Details
Option | Level | Cost
Fuel Cells | 2 | 400,000.00
Improved 105MM Cannon | 10 | 10,000,000.00
Improved Batteries | 0 | 0.00
Improved Camera | 1 | 62,500.00
Improved Diesel | 1 | 500,000.00
Improved FBCB2 | 2 | 833,333.30
Improved Flash Detector | 2 | 160,000.00
Improved FLIR | 1 | 400,000.00
Improved Glint Detector | 3 | 720,000.00
Improved SINCGARS | 3 | 450,000.00
Improved Structural Alloys | 1 | 1,250,000.00
Total | | 14,775,830.00

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Time Simulation Software Object

- Developing simulation tool for modeling large number of platforms
- Each platform is an individual object
  - Object is a collection of elements such as:
    - Subsystems
    - Components
    - Failure Modes
    - External Condition states …
  - Object can have multiple functions:
    - Mobility
    - Communications
    - Sensing
    - Firepower …
  - Object provides:
    - Real-time status of any MOE
    - Probability of maintaining MOE to end of mission
    - Most likely problem areas
    - Simulation statistics …
  - Object is a state model

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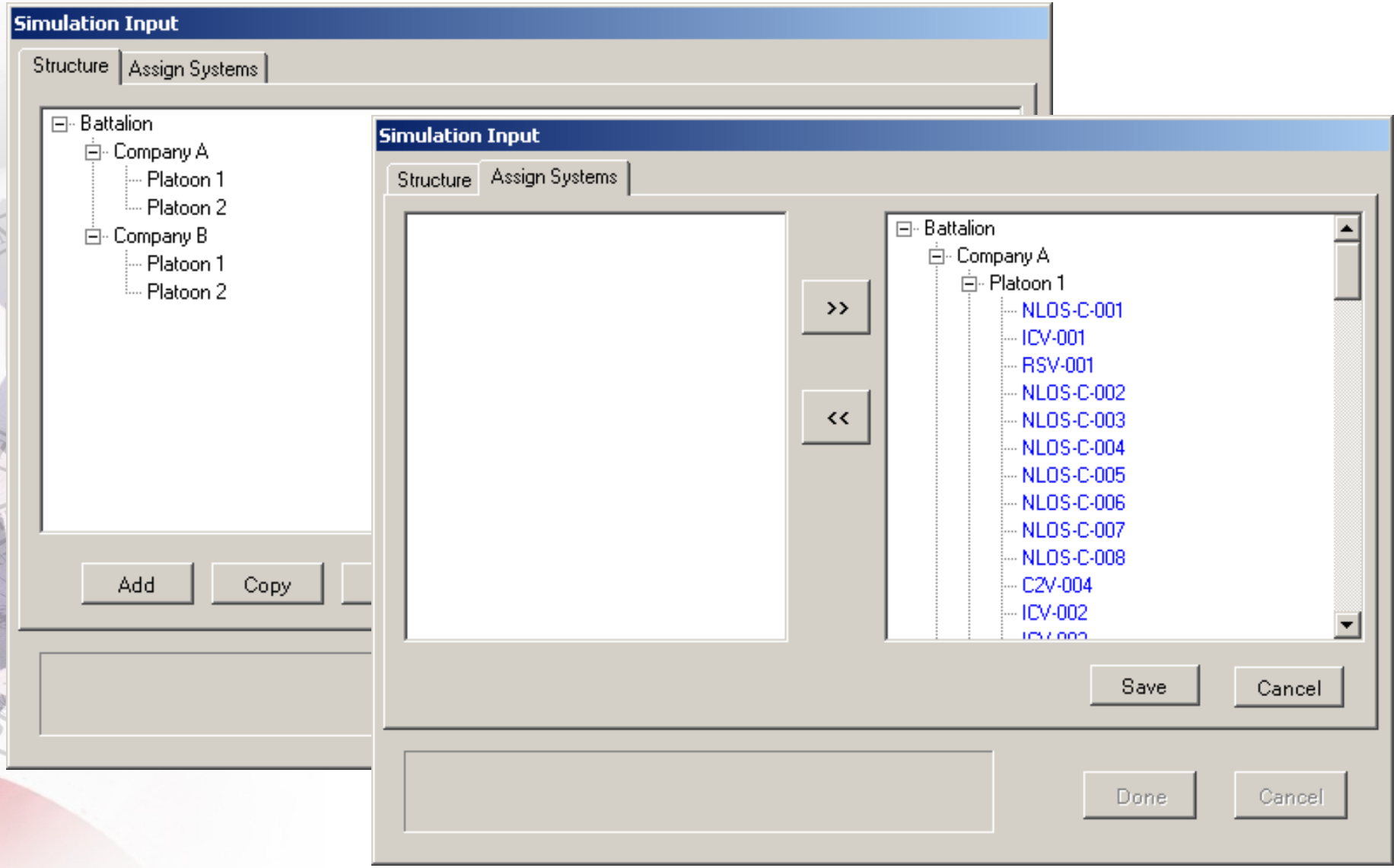
Battalion Structure



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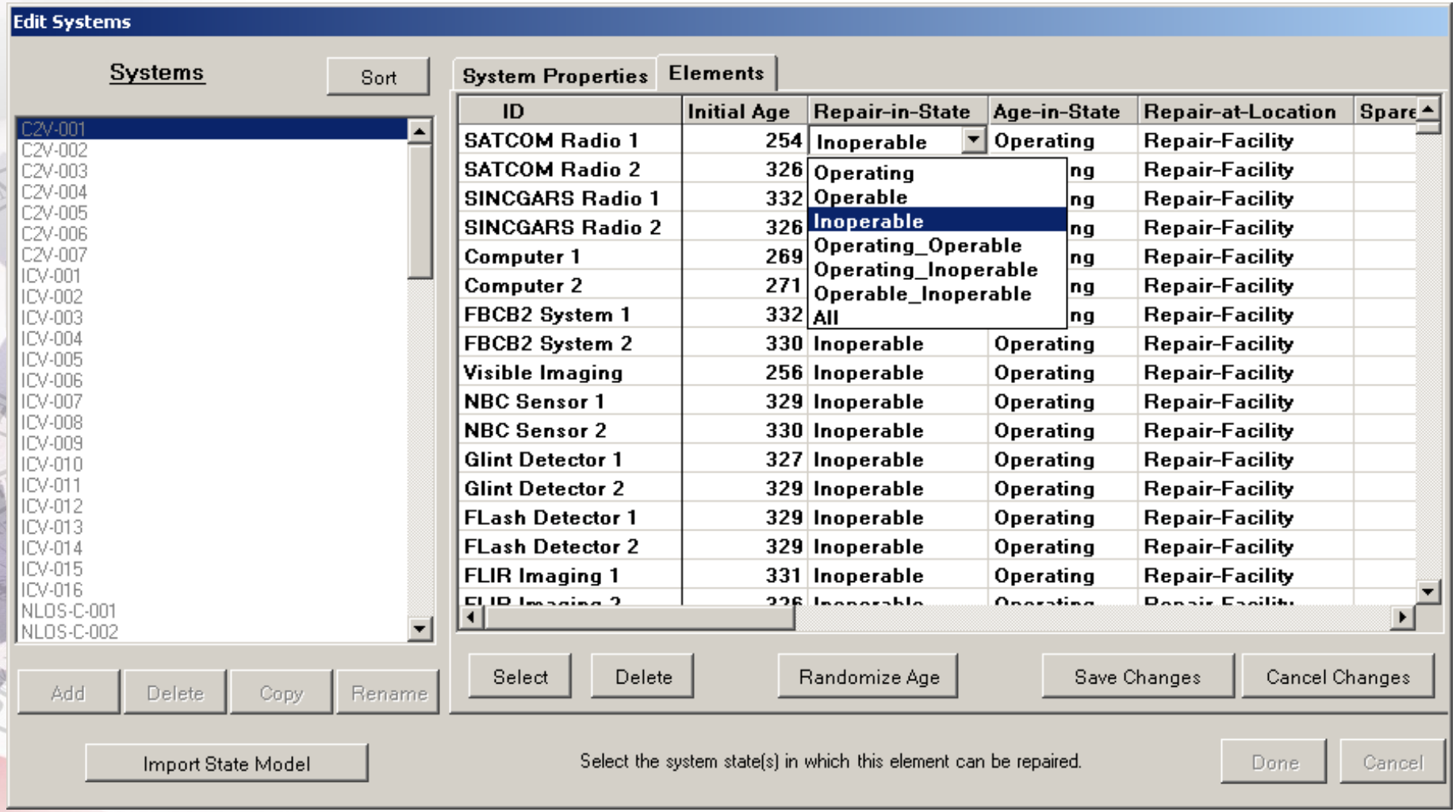
System Elements – Repair in State



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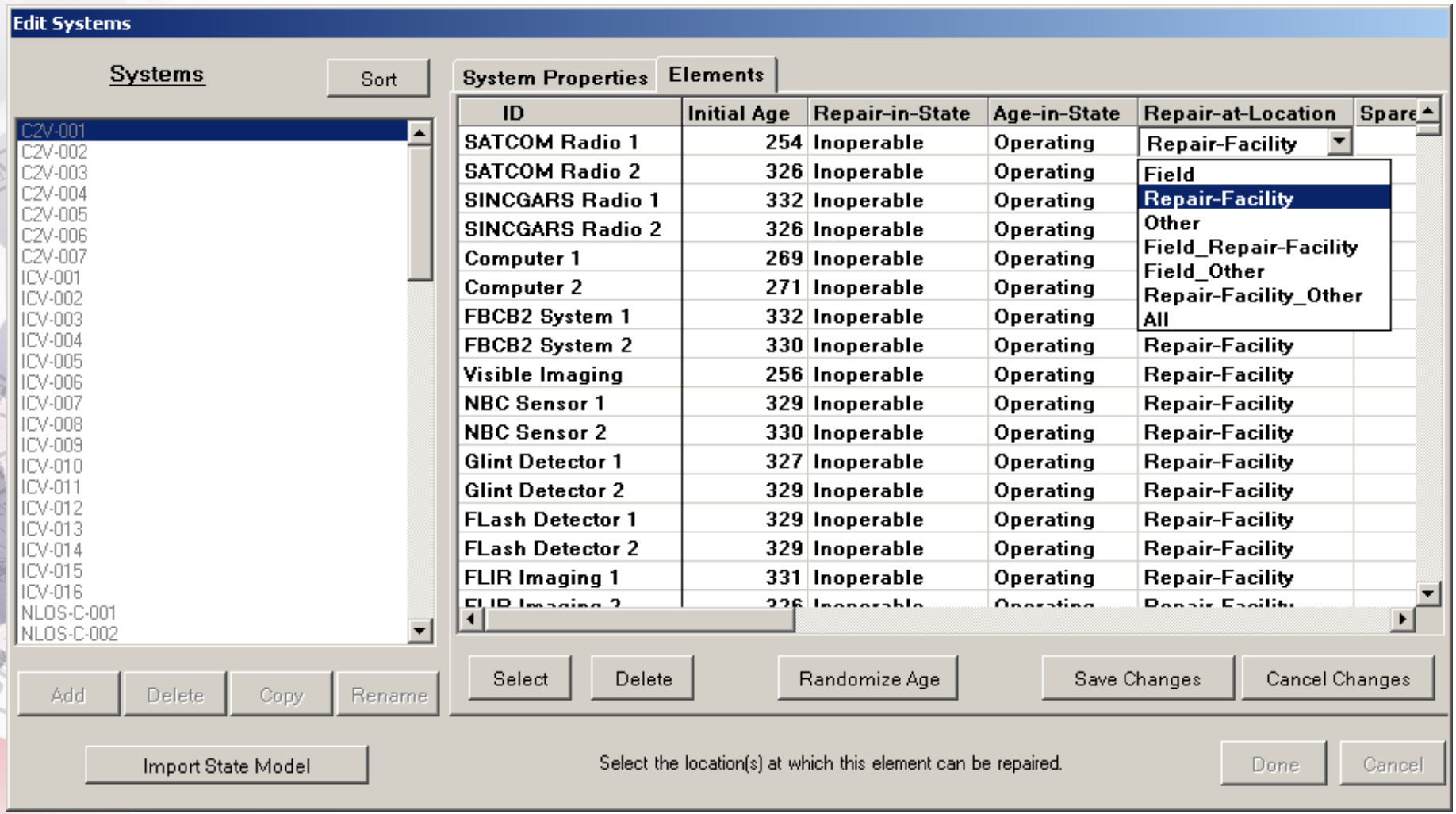
System Elements – Repair at Location



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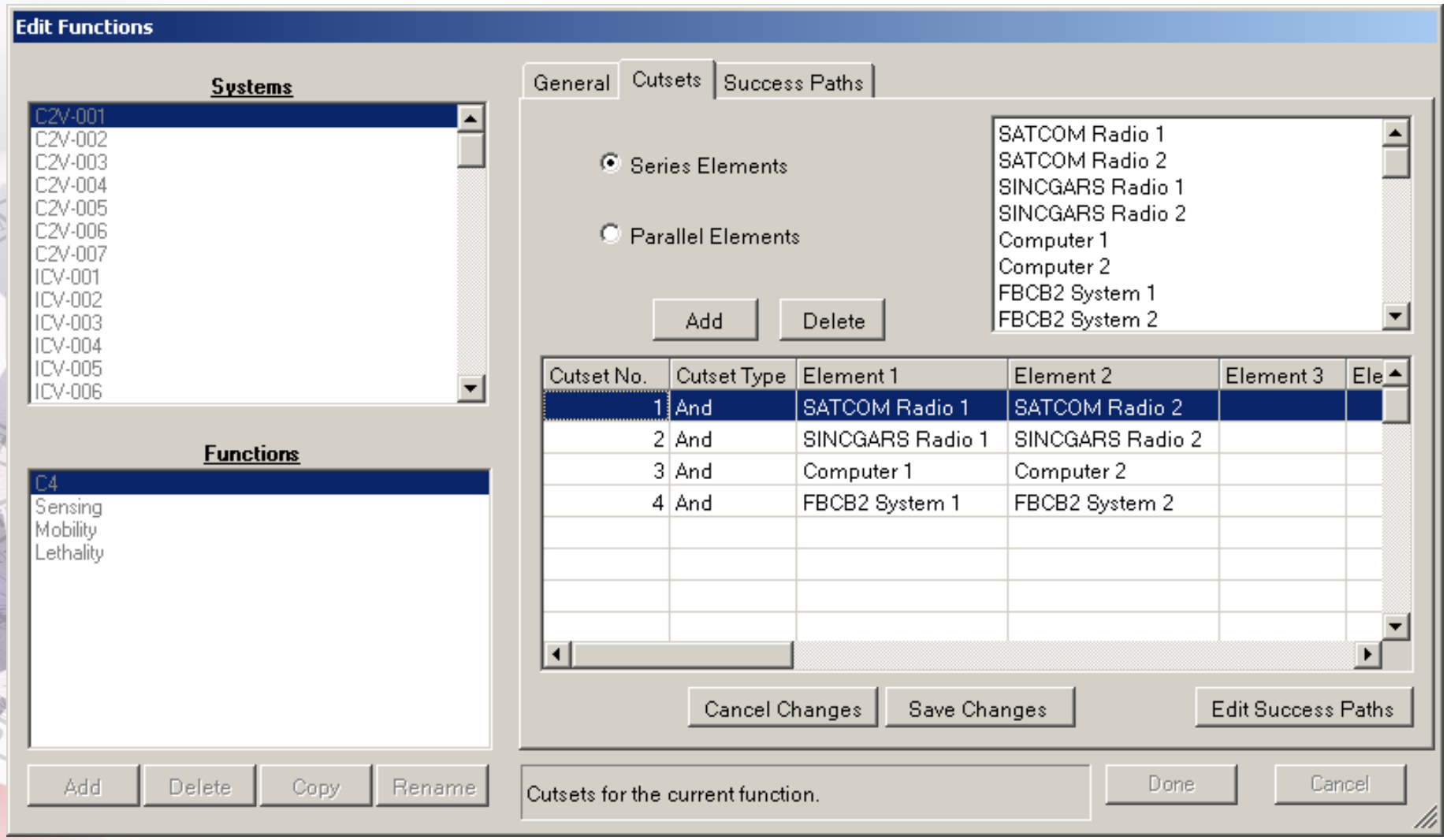
C2V C4 Function Redundancy



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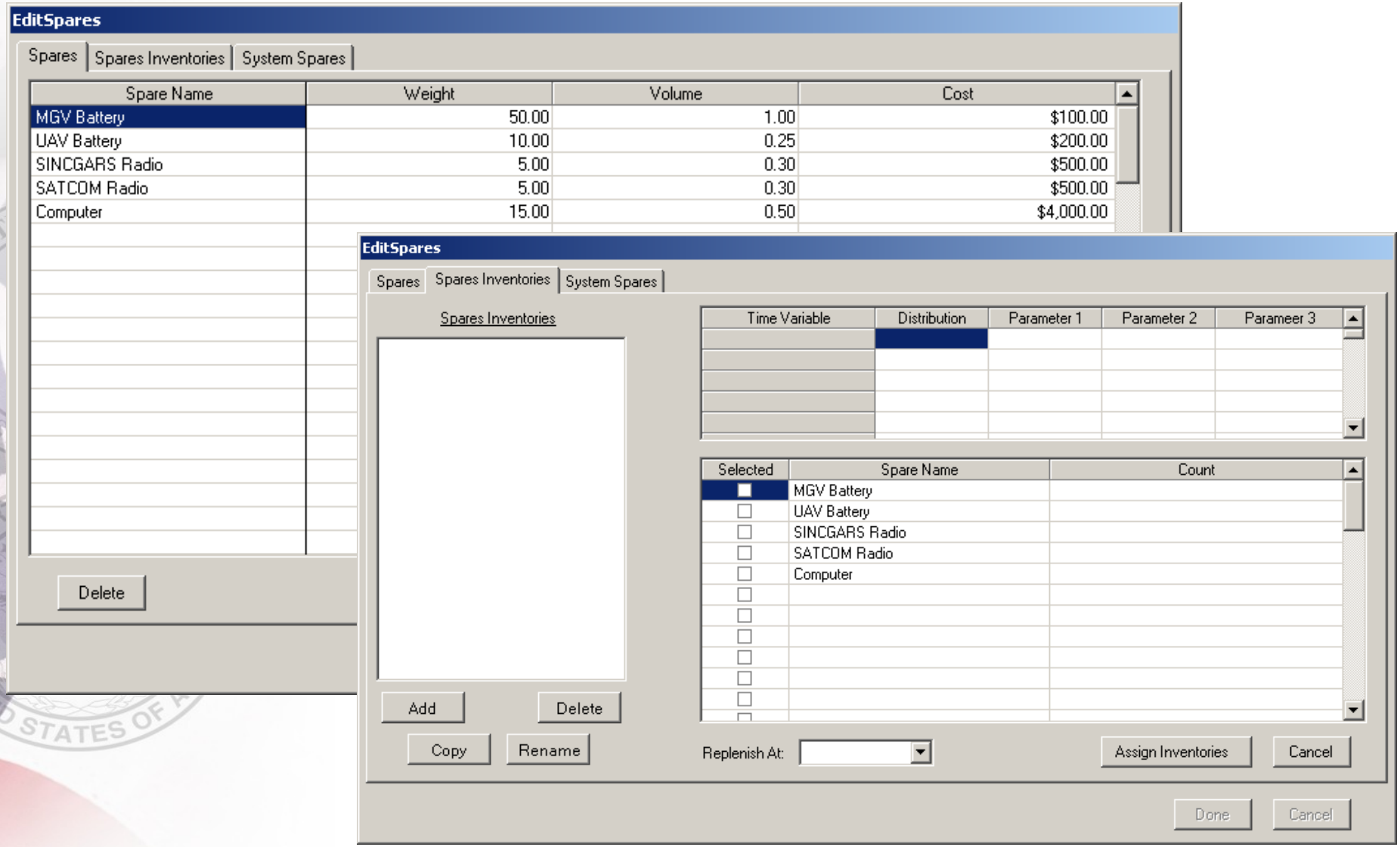
Spares



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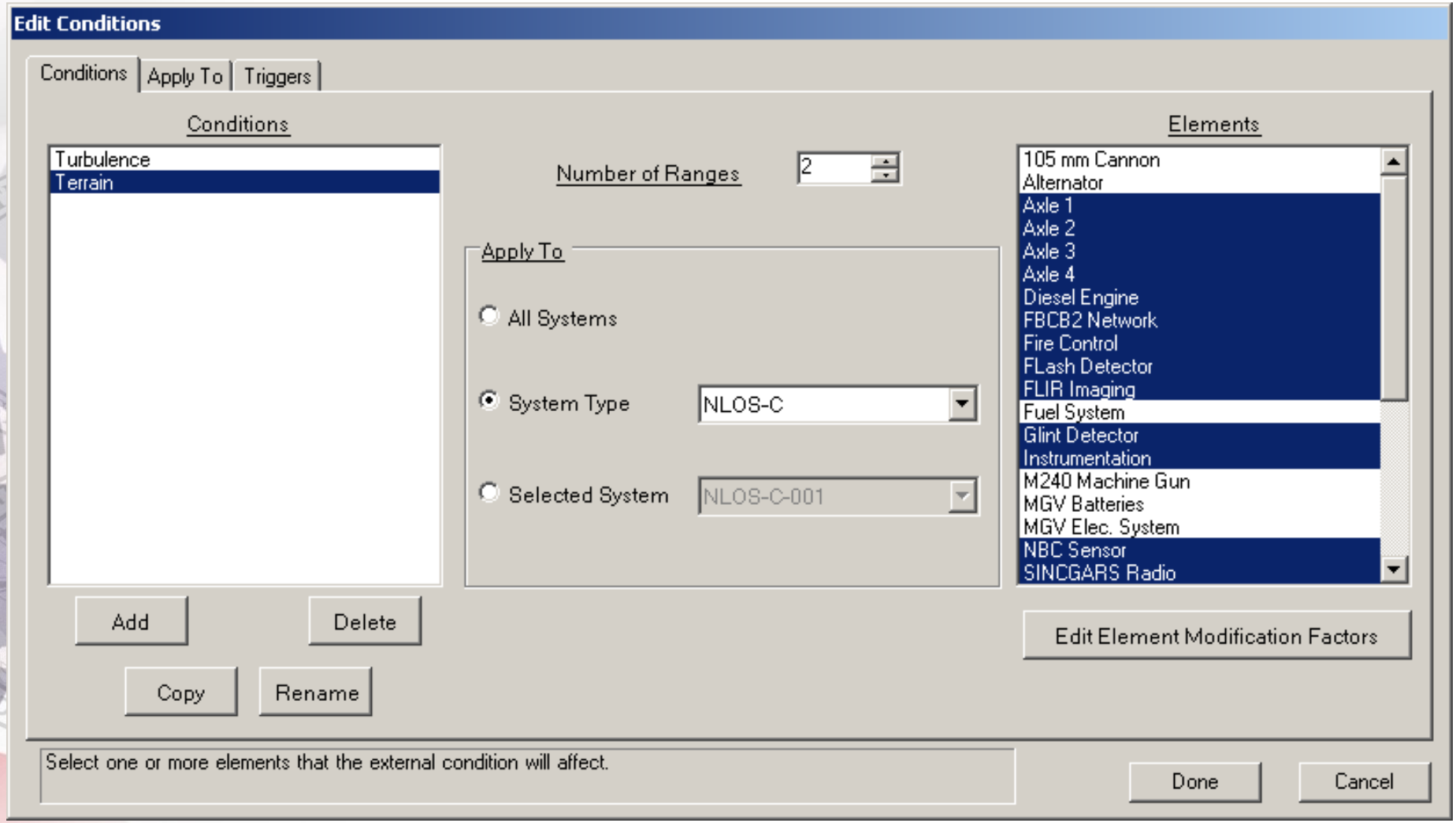
External Conditions



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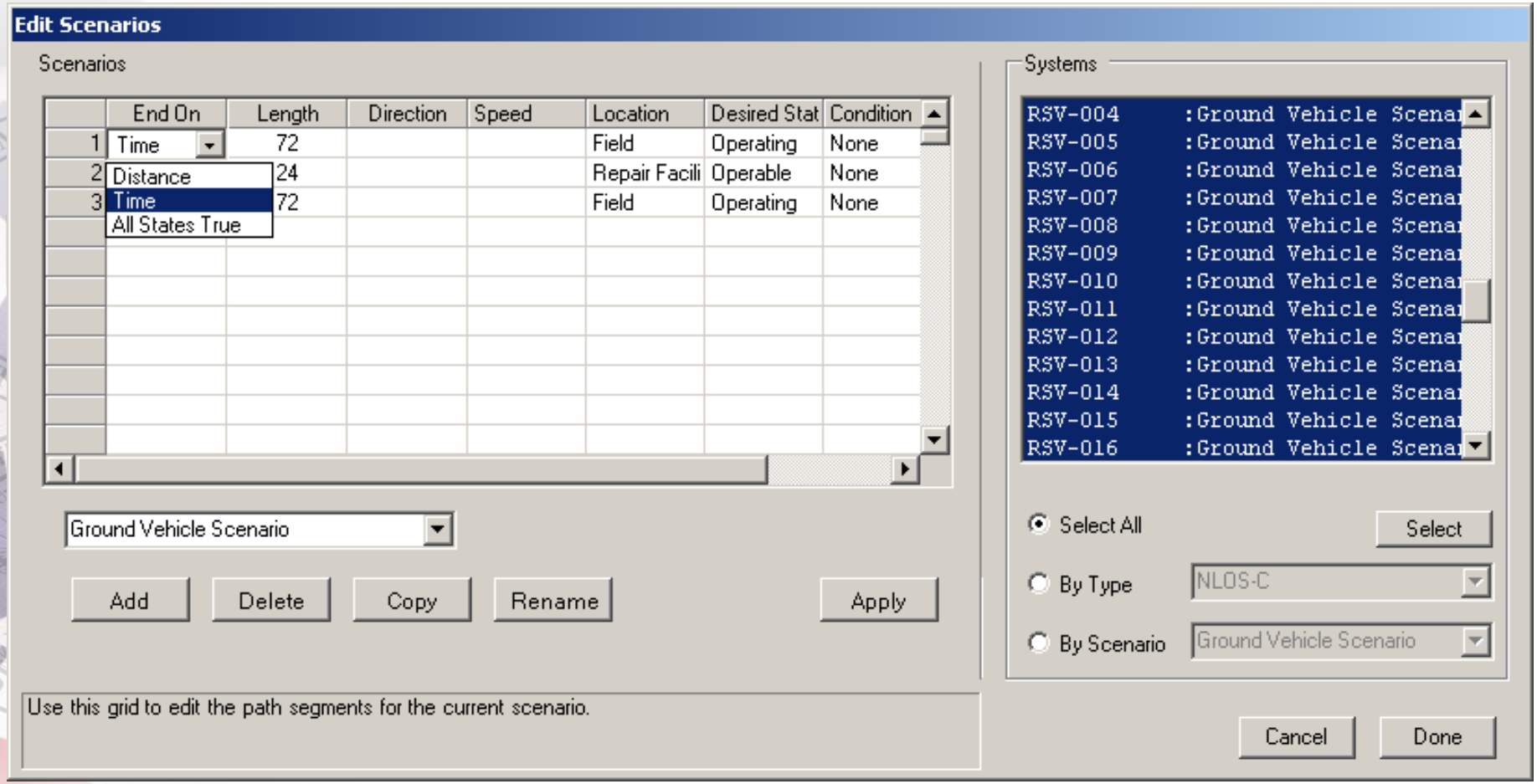
Ground Vehicle Scenario



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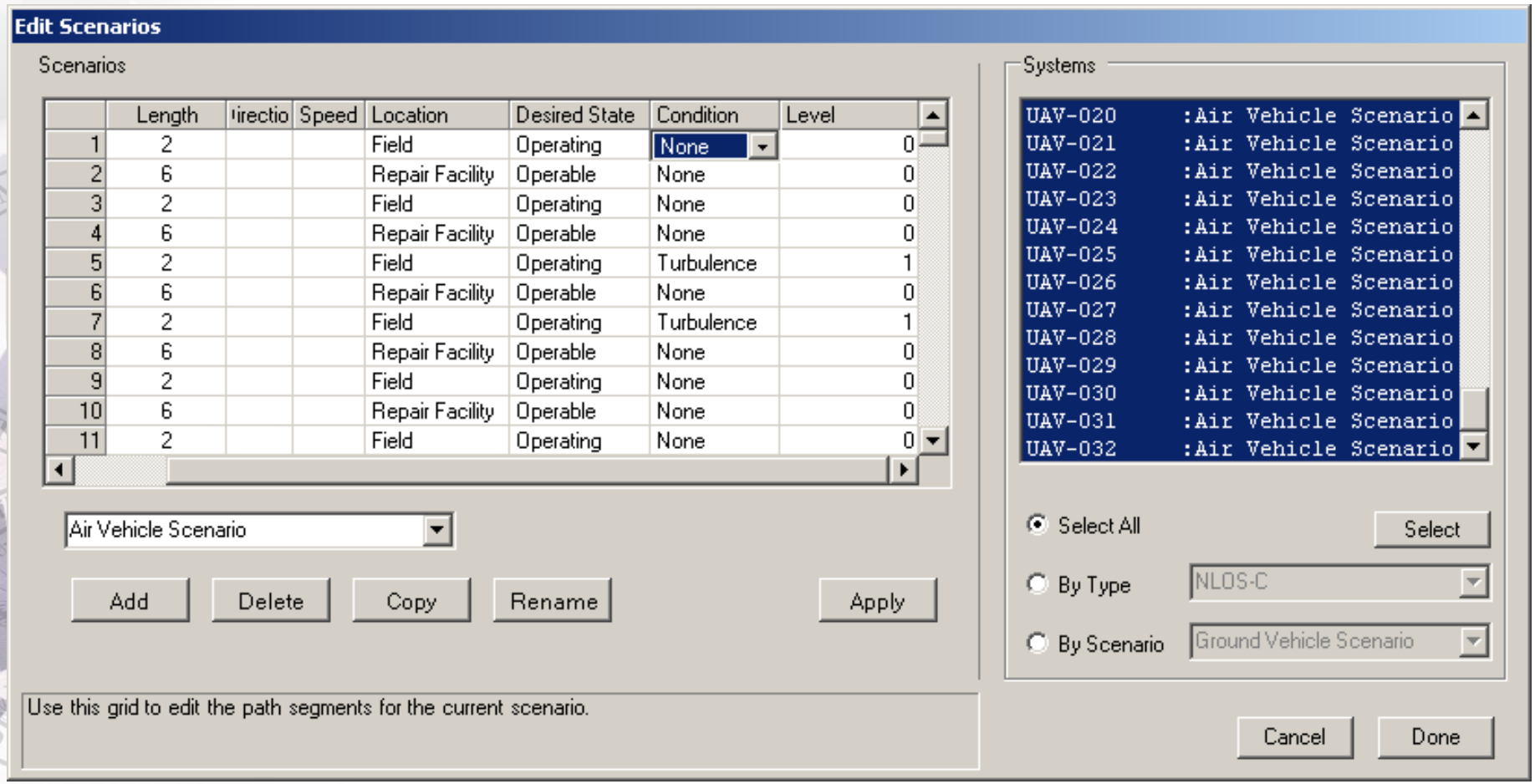
Air Vehicle Scenario



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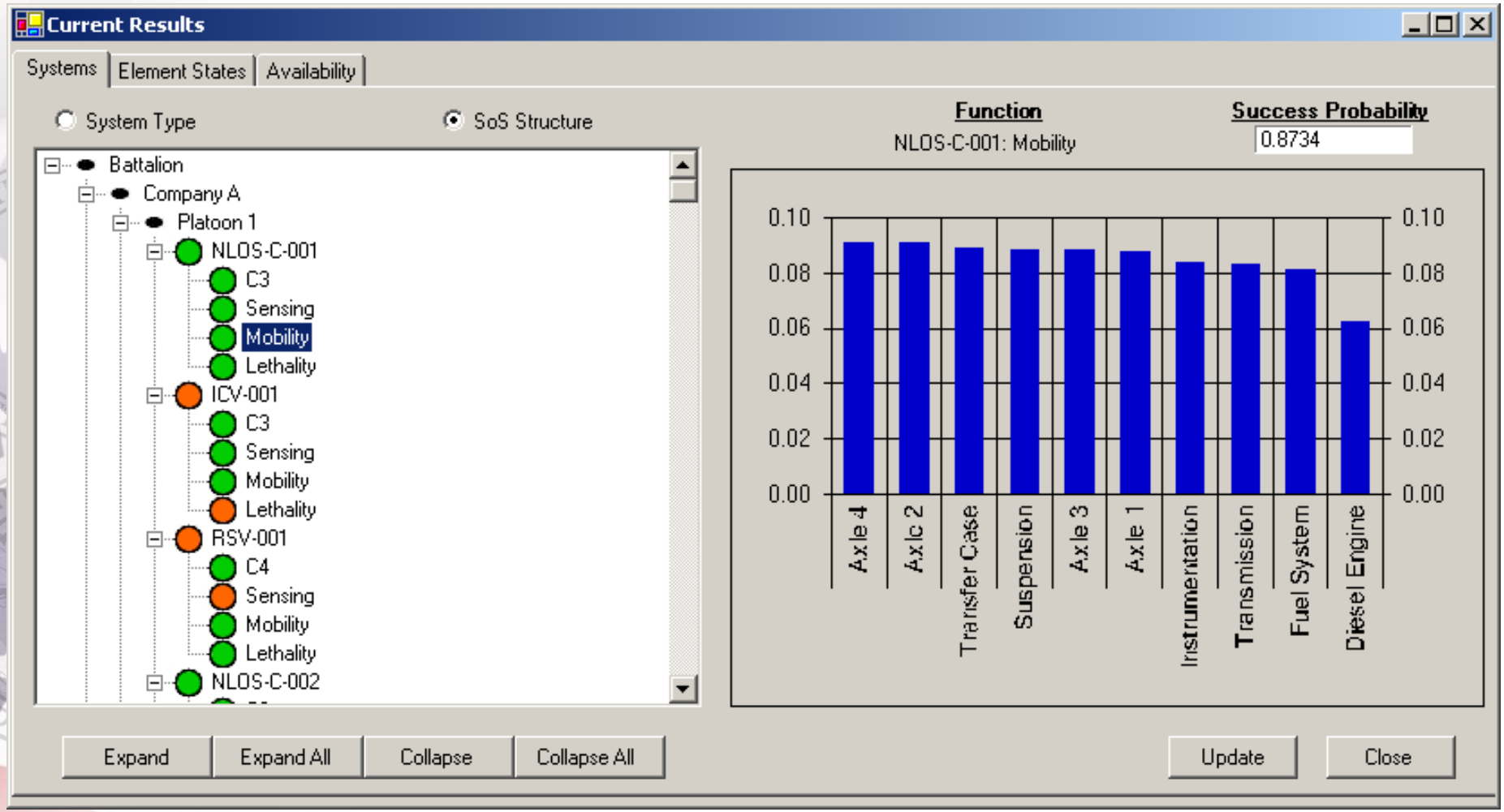
Simulation Time-Step Output



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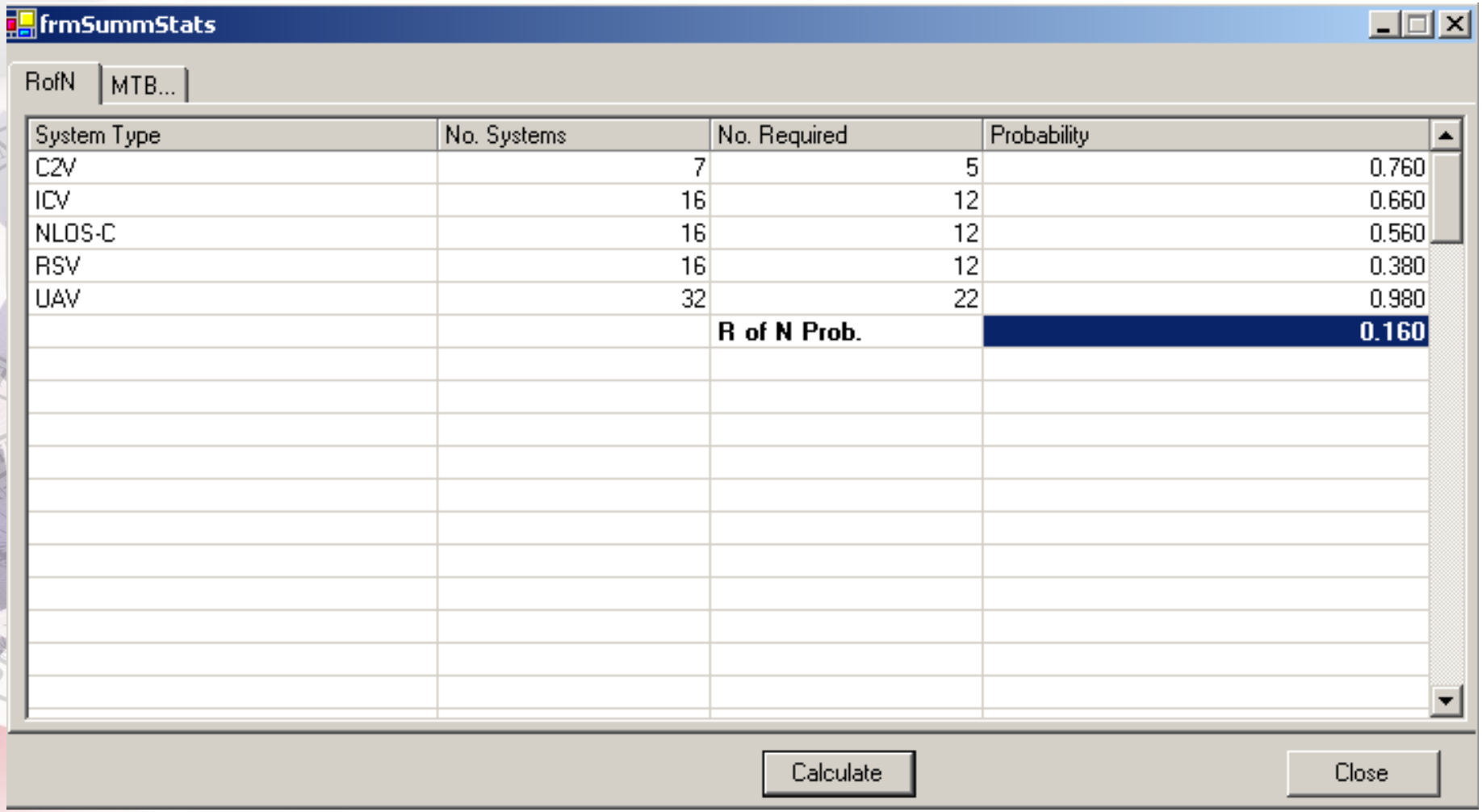
Mission Required Vehicle Probabilities



System Type	No. Systems	No. Required	Probability
C2V	7	5	0.760
ICV	16	12	0.660
NLOS-C	16	12	0.560
RSV	16	12	0.380
UAV	32	22	0.980
		R of N Prob.	**0.160**

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SoS Methodology

- **SoS assessment methodology based on:**
  - **Previous FCS SoS assessment programs for DARPA and JVB**
  - **Internal SoS modeling and analysis research program**
  - **Extension of Sandia suite of RAM modeling, analysis, and optimization tools**
  - **Continued development of state modeling tool**
    - **Models multiple MOEs**
    - **Supports optimization across multiple platforms and multiple MOEs**
    - **Generates time simulation software object**
      - **Each platform is a state model object**
      - **Each state model object provides**
        - Real-time status of any MOE
        - Probability of maintaining MOE to end of mission
        - Most likely problem areas
        - Simulation statistics
        - Handling of on-board spares
  - **Development of time simulation tool for modeling large number of platforms**
    - **Incorporates state model objects into time-simulation environment**
    - **Creates and duplicates multiple platform types**
    - **Describes MOE/functional areas for each platform type**
    - **Scales up to large number of systems**
    - **Describes scenario conditions**
- **Goal is to develop SoS Modeling and analysis suite that integrates state modeling with Sandia RAM toolset and time simulation**

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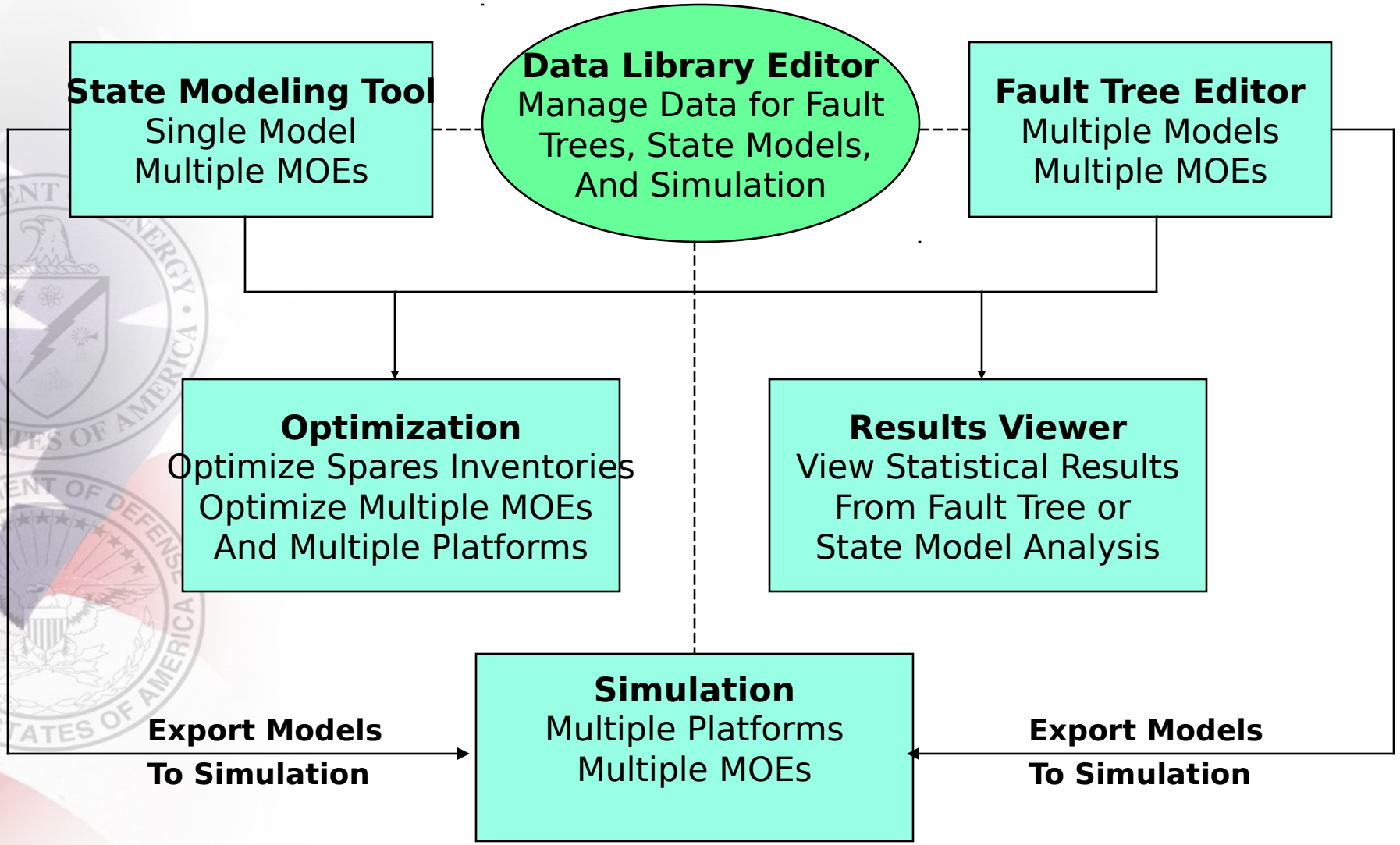
Next Generation Analysis Suite



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Backup

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Technologies and Customer Base in Supportability

- Modeling & Simulation
- Design for Reliability / Maintainability
- Optimization/Genetic Programming
- Prognostics & Health Management
- Automated Assembly/Disassembly
- Supply Chain Management
- Spares Inventory Optimization
- Technical Risk Management
- Sensitivity / Uncertainty Quantification
- Human Factors Engineering

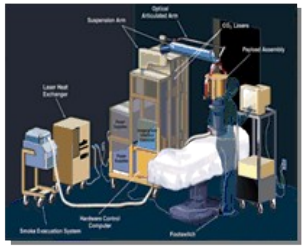
Defense

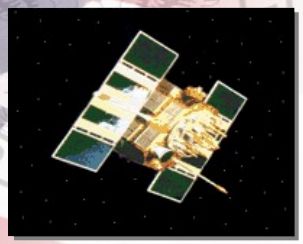
Machine Tool

Farming

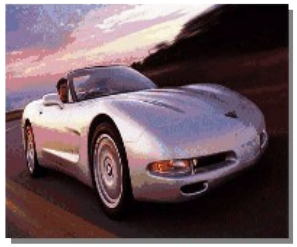
Semiconductor

Boating


Health Care


Satellites

Aviation


Automotive

Nuclear Power

Power Grid

Textile

Tools & Technologies Validated Through Broad Use

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Optimization Modeling

Modeling Tools

- Fault Trees/Block Diagrams
- Discrete Event Simulation
- State Space Modeling
- Agent-Based/Object Oriented
- Finite Element

:

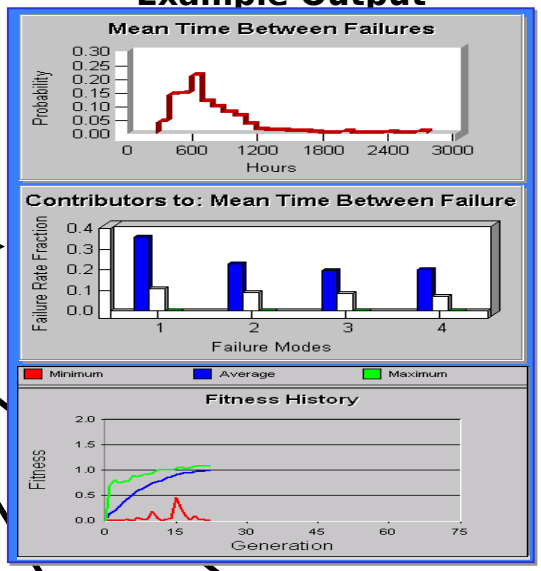
:

:

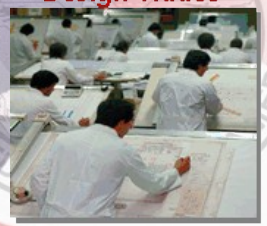
System Model

Optimization Module

Example Output



Design Trades



Resource Allocation

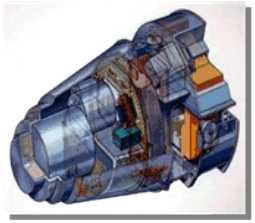
Test Strategies

Supply Chain

Spares Inventory

Maintenance

Mods/Retrofits



Our Optimization Modeling Supports all Aspects of the Life Cycle

Sandia National Laboratories